AD-A171 793 TRANSITION AND TURBULENCE CONTROL OF BOUNDARY LAYERS IN WATER(U) CALIFORNIA INST OF TECH PASADENA DIV OF ENGINEERING AND APPLI.. H W LIEPMANN ET AL. 01 JUL 86 1/1

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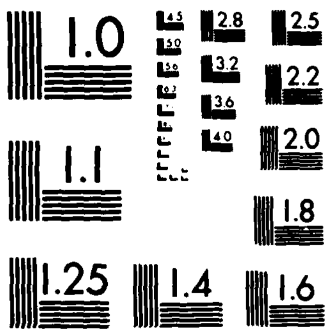

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Final Technical Report

Contract N00014-81-K-0551, NR 657-715

TRANSITION AND TURBULENCE CONTROL OF BOUNDARY LAYERS IN WATER

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This research contract was originally awarded for the period 1 June 1981 to 30 September 1982. It was renewed for the period 1 October 1982 to 30 September 1984, with two no-cost extensions to 31 March 1985 and to 30 September 1985. The work has involved three main areas of boundary-layer stability and transition:

1. Generation and Control of Laminar Instability Waves

The first area of research was a study of the generation and control of two-dimensional instability waves (Tollmien-Schlichting waves) in laminar boundary layers in water. The technique exploits the strong dependence of viscosity on temperature and the consequent distortion of the velocity profile when local non-steady temperature fluctuations are introduced at the wall. In the present research the disturbances were produced by non-steady heating of spanwise strips inserted in a flat-plate model. Supporting instrumentation included power amplifiers, wall-stress sensors, and a microprocessor controller and data system.

Initial measurements confirmed that amplification of laminar instability waves occurs over many boundary-layer thicknesses. This fact makes it possible to introduce instability waves into the flow at one station and to modify their amplitude by introducing similar waves at some downstream station, with a suitable choice of phase displacement. What is implied is the possibility of closed-loop control. Development of the required combination of disturbance generators, sensors, and control electronics was a major effort during the research. An active feedback-control system using a single heater and a single sensor was used to modify natural instability waves in real time. The transition length could be increased or decreased by about 25 percent by using a modest amount of electrical power.

Publications

Nosenchuck, D.M. Passive and active control of boundary layer transition. Ph.D. Thesis, California Institute of Technology, 1982.

Liepmann, H.W., Brown, G.L., and Nosenchuck, D.M. Control of laminar-instability waves using a new technique. J. Fluid Mech. 118, 187-200, 1982.

Liepmann, H.W. and Nosenchuck, D.M. Active control of laminar-turbulent transition. J. Fluid Mech. 118, 201-204, 1982.

2. Passive Control of Turbulent Spots and Turbulent Boundary Layers

The original proposal contemplated a possible generalization of the control methods described in Section 1 to control of turbulent flow, by using small three-dimensional heater elements. Some preliminary attempts showed that this proposal was too ambitious, for two reasons; one is that the control devices would have to be extremely complex, and the other is that the mechanisms of turbulent flow are not well enough understood.

The objective was changed to a study of turbulent spots generated by small local heated elements. The effect of large-eddy manipulator blades on the spots was observed as a function of blade geometry, using surface elements for measurement of wall shearing stress. A substantial reduction in surface stress was found in the region of flow associated with the large vortex within the spot. In a tripped turbulent boundary layer, drag reductions comparable to those of other investigators were found. A major conclusion, different from the conclusions of other authors, was that large-eddy manipulators are not low-drag devices, and that an important part of the drag reduction is associated with local transport of low-momentum fluid in the wake of the manipulator blades.

Publications

Taylor, S. The effects of large-eddy manipulator devices on the turbulent spot and the turbulent boundary layer. Ph.D. Thesis, California Institute of Technology, 1985.

3. Oblique Instability Waves

Recent experimental and theoretical work has shown that oblique instability waves can be effective generators of the three-dimensional large disturbances that immediately precede the appearance of turbulence in laminar boundary layers. A programmable 32-element spanwise heater array and the supporting electronics were fabricated to generate three-dimensional waves of essentially arbitrary planform. For carefully constructed two-dimensional waves, the growth rates follow the linear theory up to perturbation amplitudes of at least six percent, despite some generation of higher harmonics. For oblique waves, the direction of propagation, the phase velocity, and the region of instability in frequency-Reynolds number space are all essentially independent of the wave angle of the disturbance. Nevertheless, oblique instability waves were found to have several striking properties. Effects of non-linearity were again found to be not as important as effects of three-dimensionality. All three components of the vorticity can be important. In certain regions of parameter space (angle, frequency, amplitude), oblique waves can be much more unstable than two-dimensional waves. In the late stages of the instability, period doubling is observed, unlike the two-dimensional case. The phenomenon may be vortex pairing or it may be the evolution of a staggered vorticity pattern. Research on these questions is continuing.

Publications

Robey, H.F. III The nature of oblique instability waves in boundary layer transition. Ph.D. Thesis, California Institute of Technology, 1986.

Robey, H.F. On the use of a phased heater array for the controlled excitation of arbitrary three-dimensional perturbations in a laminar boundary layer. (Submitted to "Experiments in Fluids".)

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